Integration of Software Tools into a Multi-disciplinary Undergraduate Student Design Project

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Abstract

This paper presents a pilot scheme for the integration of modern state-of-the-art turbomachinery design tools into project-based education of undergraduate students. This effort has been part of a larger international gas turbine project (IGTP) in which undergraduate students from a German (TU Berlin), a French (EC Lyon) and a Swiss (ETH Zurich) University undertook the design of the cooling system for the high pressure turbine of a 30,000lb thrust aeroengine. In addition, the goals of the project included self-organization and distribution of the tasks by the students themselves, the improvement of their communication skills and teamwork.

At the Swiss Federal Institute of Technology (ETHZ) the design-task was offered to a limited number of students, organized as a project team. Tasks were distributed related to the tools, in particular CAD, CFD and FEA. Appropriate short duration training in the software packages, was provided. The initial design tasks were performed through manual calculations by following traditional lecture notes. The conceptual design was followed by more sophisticated three-dimensional design tasks using computer-aided techniques. Finally, the students were assessed continuously with respect to their technical contribution, working techniques and interaction with their peer group at national and international level. They were also probed regarding their opinion on various aspects of the project using interviews and forms. These surveys have been evaluated together with the opinion of the academic staff in order to form future directions.

For the planning the students had to consider the engine as a whole before distributing the tasks individually. This enabled them to handle the design requirements successfully through effective use of the available software tools. An increased effort of the academic staff was registered in comparison to conventional teaching methods. However, a substantial technical and communicative growth of the students was evident in this early introduction into the application of engineering knowledge to a high technology application.

Introduction

The competitive market and high technology of aircraft engines forces companies to use highly sophisticated computational methodologies to meet today's development rate. The turbomachinery education program at the ETH Zurich has recently undergone a refinement aiming to create a modern teaching program that prepares students for an engineering career and includes a wide range of state-of-the-art topics in line with the interests of the relevant industry. The traditional lecture series have been reorganized to meet the demands of the ever-increasing use of computational methods within the design process. To prepare the integration of commercial design software packages into the lectures and the exercises of "Turbomachinery Design" course, a pilot phase was performed to investigate student interaction with complex software systems and optimize the design of the future.

Based on the experience of the Jet Propulsion Laboratory of Technical University of Berlin (TU Berlin), performing a similar project on national level[6], the IGTP raised the effort to international level. The tasks were distributed between student teams at the Turbomachinery Laboratory of ETHZ, the Turbomachinery Group of École Centrale de Lyon (EC Lyon) and TU Berlin. Each University team was responsible for one aspect of a complex design, with appropriate interfaces between the teams to ensure that the overall design meets the intended specifications. It also involved mentoring industrial partners from Rolls Royce Deutschland, MTU, SNECMA and Alstom Power. The project covered a two-semester period with regular telephone conferences and meetings with other team members.

The main theme of the project at ETHZ was the design of the cooling system of the HPT for a 30,000lb-thrust turbofan two-spool aeroengine. The project team consisted of five students and a student project leader, an academic coordinator and supervisors, as well as industrial mentors from Alstom Power. A realistic scenario of the design process of an aircraft engine, however, cannot be transferred one-to-one into the student classroom environment[9]. In this project, an attempt was made to follow the actual design process as much as possible, simplifying the process just sufficiently to keep it manageable within the academic framework. The introduction of complex software packages in the frame of this project was aimed at both probing the students' receptivity as well as enabling them to perform a few iterations on the main tasks, based on the experience gained. Bringing teaching methodologies up-to-date followed the roadmap to a future education in turbomachinery[7]. A marked observation of that work was that in German Universities design projects should be performed in interdisciplinary academic-industrial teams and communication and presentation skills could be improved.

Objectives within the framework of engineering science at ETHZ

After the first two years of background courses, the mechanical engineering students may choose two fields of specialization. In each of these areas, a research and design project is to be completed to promote independent work and creativity. The project topics may be centered on the Institutes research area and can be carried out in association with industry. Within the IGTP a limited number of students performed their design project, following the formal lectures, exercises and laboratory sessions in parallel. The coordination of the IGTP and supervision of the individual design tasks of the students remains completely within the academic domain. The participating industrial partners function as mentors and consult the student team on specific items and provide a direct link to standard industrial practices.

The strategic aims of ETHZ are the promotion and maintenance of quality in teaching at the highest international level. In order to support institutes in using advanced learning techniques, a funding project was initiated by ETHZ to promote the:

- Use of new information technologies in teaching
- Gain effective knowledge for advanced studies and interdisciplinary competence
- Self responsible learning techniques and self organized arrangement of studies
- Problem oriented working
- Improvement of student social competence
- Improvement of collaboration between universities abroad and ETHZ

In addition to the aforementioned goals, the current project aimed to fulfil the following academic targets for the students:

- Understand the design process of a complex device
- Obtain an overview of the disciplines and their interactions
- Achieve project work skills: self-organization, team work and time management
- Exercise industrial working procedures and electronic communication techniques
- Learn about cultural differences and improve communicative competence.

Integrating computer-aided tools into the turbine design process

The cooling system of the high pressure turbine of a 30,000 lb thrust two-spool bypass turbofan aeroengine was the main focus of the design exercise. Cruise conditions were assumed initially and some of the main design parameters are listed in Table 1. The students summarized the design process in a flowchart shown in fig. 1, having experienced the iterative character of the tasks and the necessity of return loops.

Flight condition	ISA Ma=0.8	Hub-tip ratio	< 0.9
Thrust	30,000 lb	Trailing edge thickness	≈ 0.05 mm
Bypass ratio	5.5	Solidity	0.8 – 0.9
Nozzle guide vane metal angle	65° –75°	Turning Past Throat	5° – 10°

Table 1. Main Design Parameters

An one-dimensional hand calculation of the cycle was the basic tool to understand the influence of the individual parameters. The best thermodynamic design point of the cycle was obtained through an optimization process. The commercial gas turbine performance program GasTurb[8] was used to support the time consuming systematic parameter variation. The PC-based program includes several engine configurations and component performance maps. Output data are available as enthalpy-entropy diagrams, velocity triangles, flight envelopes etc. The students were provided with a user-manual and a short introduction before proceeding independently.

The initial blade geometry design was based on the hand calculations. Tangential velocity and radial work distribution were varied to match the requirements such as power output, degree of reaction and tip speed. These hand calculations were also essential in minimizing the risk that the students would proceed to complex computational tools without understanding the fundamental physical limitations and assumptions.

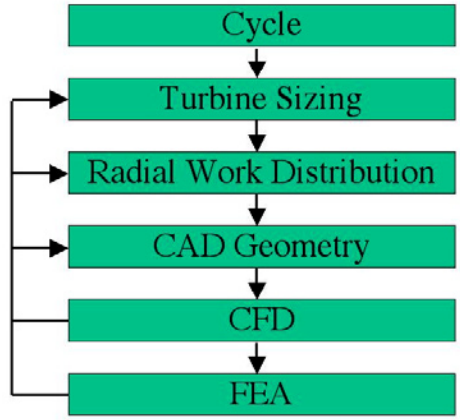

Fig. 1. Flowchart of the design process

For the optimization of the blade design the Educational Agile Engineering Design Software System was used. It consists of various modules including meanline analysis, 3D blade design tools as well as a CFD package and a FEA model generator. In academic environments, the difficulties associated with input-output issues are often underestimated, as more emphasis is placed to the scientific issues. In the current set up, students were guided to concentrate on the process as a whole rather than focussing on details of complex interfaces. Having experienced the difficulty of the task as well as the effort required for manual calculations, the students realized that a good design requires an excellent overview of all disciplines involved.

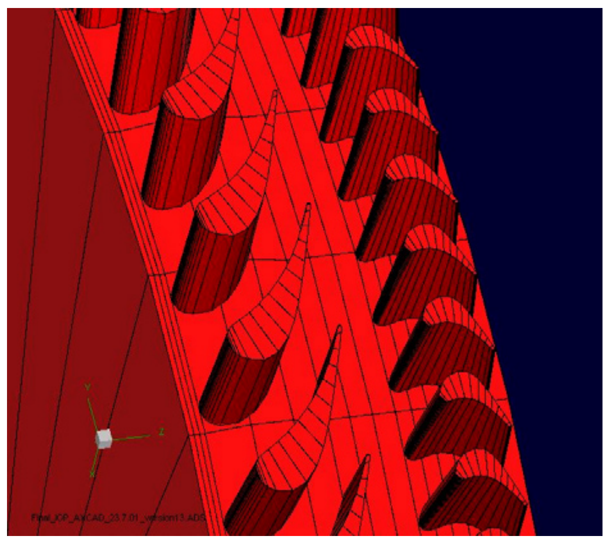
Fig. 2. Section of the circumference of the obtained stage configuration

The preliminary design was produced based on the through-flow design tool for axial machines. Students were asked to optimize the initial blade geometry including blade angles, mean radii, passage heights and velocity triangles leading to the desired velocity and pressure distributions for the application. The CAD module of the software package provided geometry generation capabilities for a two- and three-dimensional description of rotors and stators. Loading calculations and quasi three-dimensional blade-to-blade flow calculation were performed. This tool enabled the students to elaborate on a three dimensional model (fig. 2).

The integrated CFD module of the design software incorporates pre- and post- processing tools and allows design optimization with a three-dimensional Navier-Stokes solver[2,4]. Geometry data are transmitted from the CAD module without user intervention and boundary conditions are taken from the through-flow results. A suggestion for solver settings, grid size and stretching factors is given to simplify and complete the settings for the given test case[2]. With regard to cooling, various loss-models were made available to estimate the respective mass flows and total pressure loss.

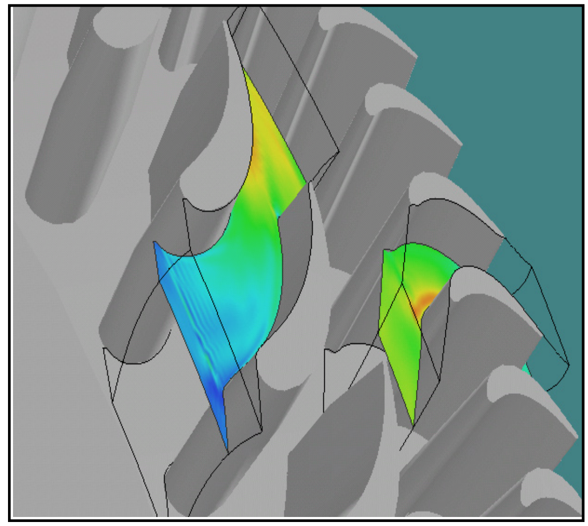

Fig. 3. Prediction of the total pressure distribution through the stage at mid span

As the students involved, had little experience with the use of commercial CFD tools, the aforementioned data transfer facilitated the start up of cases and students were able to concentrate on the effect that changes in the design parameters had on the results. Figure 3 shows a first plane visualization of the total pressure distribution. Although some of the basic rules of CFD application were not fully appreciated by the students at that time, the position of CFD in the design process was made clear. Further instruction in CFD was undertaken during the second semester of this project, using the guidelines of standard turbomachinery lecture series in CFD[5].

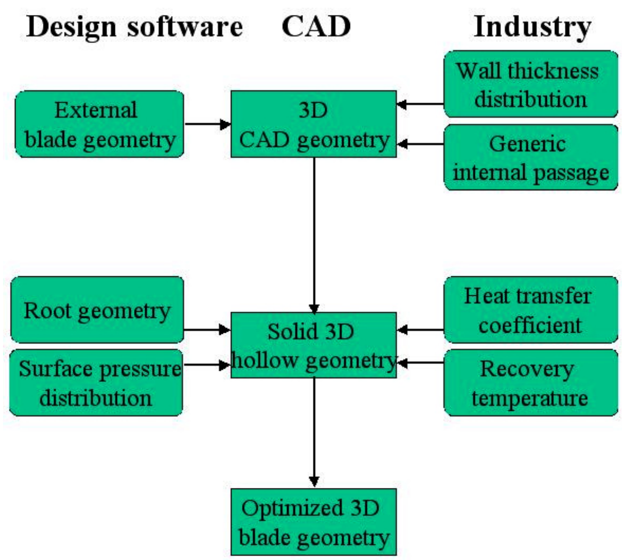

Fig. 4. Design flowchart for cooling structure

In order to handle the internal cooling structure, the external blade geometry was exported to Unigraphics (commercial CAD package). The students had past formal training and working experience in CAD in earlier semesters that facilitated its application to the current framework, too. The complex design process for the cooling geometry was initially reduced to the flowchart presented in fig.4. Industrial expertise on the manufacturing and design of such geometries was employed to obtain realistic design parameters.

At a first instant, the passage configuration was formed using rectangular ducts respecting minimum wall thickness constraints. As a result, a three-dimensional solid body was created (fig. 5). Further industrial input facilitated the optimization of the passage configuration e.g. three passages with two feeding points to increase cooling efficiency. The final product of this iteration is presented in figure 7. To reduce difficulties with contact areas, a single block simulated the blade root at the first stage of the analysis (fig. 6, 7). The surface blade geometry and pressure distribution was exported to ANSYS (commercial FEA-code), fig. 6. Additional interaction with the industrial mentors concerning heat transfer coefficient and recovery temperature provided the complete set of conditions for the FEA study.

Fig. 5. Initial 3D solid body model of the rotor blade

Fig. 6. FEA mesh for mechanical analysis

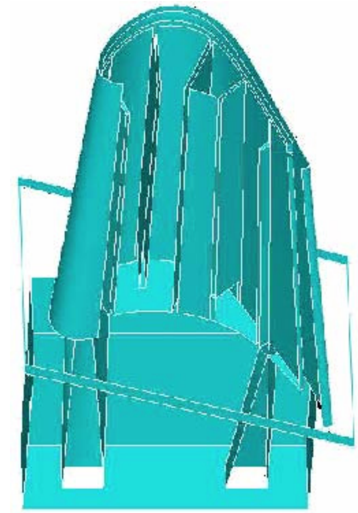

Fig. 7. Optimized solid body showing the internal cooling structure and blade root

Organizing and carrying out the project

The academic coordinator was in direct contact with the other universities and the technical professionals. The structure of supervision comprised orientation sessions for general information, training sessions for the software involved and working sessions for technical issues. Orientation sessions, first contacts to the involved partners and telephone conferences have been planned before the student project was officially launched. The agreement of four project meetings between the three universities and monthly telephone conferences in between provided an initial basic time schedule.

TO DO	April	May	June	
Literature survey				
Customer requirements				
Cycle calculation				
Introduction GasTurb				
Cycle optimization				
HPT sizing, cooling air, exhaust pressure				
Intermediate meeting				
Training Design Software System and				
Blade design (Agile)				
CFD calculation				
Blade optimization				
Sketch of internal cooling				
Preliminary Design Review				

Tab. 2 Project plan of first semester

Students are generally not prepared to self-organize after having finished the basic studies of mechanical engineering. They have little experience with project work and have hardly worked in team situations. The individual design tasks they were going to complete within the IGTP was their first experience with an independent work where other team members depended on their results and information exchange. To ease the start-up of the project, orientation sessions were lead by the academic coordinator, introducing project-working techniques, frequently used in business surroundings. The sessions also included guidelines for better presentations[1], effective technical writing and basics on how to run meetings. Rules for good teamwork[3] and effective communication[11] were practiced during working sessions in order to help running the meetings. Also, topics such as dealing with resistance to new concepts and issues related to cultural differences in international environment were addressed. The presented tools to work out a project plan were Mind-Mapping, Round Robin and Metaplan techniques[10]. Students decided to use metaplan cards to collect ideas in a brainstorming session under academic supervision. They clustered their ideas and formed a task list. Assigning timeframes to the tasks completed the project plan for the first semester. The result was remarkably abiding to industrial standards at this early stage (tab.2). However, most of the tasks were considered to be team tasks and were finally undertaken in groups of two to three students. The orientation sessions were followed by weekly common working sessions with the whole team and academic supervision to discuss technical items and check the status and critical items. In order to prepare the information exchange for the monthly telephone conferences with the other Universities, additional common meetings were planned, involving mainly the academics and if necessary technical professionals. Close to the common meetings working sessions were generally spend to prepare students presentations. A series of training sessions of approximately twenty hours was provided for the students to get acquainted to the turbomachinery design software tools. The academic staff supported the scientific issues. Besides the training sessions a hotline service via email was set-up for software related questions.

TO DO		Nov.	Dec.	Jan.	
CAD					
Optimisation of external and internal geometry					
Pressure drop internal passages					
Blending internal/external					
CFD					
Geometry generation					
Grid generation					
Computation adiabatic/isothermal					
FEA					
Geometry generation, external, internal + root					
Mesh generation, Boundary Conditions					
Mechanical stresses, Eigenfrequencies					
Thermal stresses					
Final Design Review					

Tab. 3 Project plan of second semester

Details of the design of the internal cooling passages were addressed in the second semester. Accordingly, the project plan was set up in the beginning of the second semester. Tasks were assigned to individual students (table 3). The structure for supervision changed accordingly to regular bilateral meetings between the supervisor and the student. Additionally, the students reported to the project leader and self-organized regular meetings among themselves to review the status. The common working sessions were reduced and only performed to prepare the monthly telephone conferences.

Student Interaction. The academic point of view

The project was planned as a pilot phase for the introduction of turbomachinery design software into conventional courses and exercises. This pilot phase is considered to be very successful. Students were acquainted to the computer software very well and appreciated the level of sophistication. The tasks will be adapted to timeframes of exercises and will be spread over four semesters of turbomachinery education at ETHZ. The complexity of the tasks does not necessarily have to be reduced provided that the timeframe is enlarged, adequately. With the new generation of students trained in the design software tools in the lectures and exercises, future design projects will have strong impact on the development of engineering judgement. From the academic point of view, the students gained widespread multi-disciplinary design experience valuable for their first industrial placement. Being able to visualize changes in the design at each stage of the process, implicitly led to a deeper understanding of the importance and influence of each parameter. The difference between students attending only the lectures and the participants of the project was clearly observed. Even in cases of mechanical engineering students with a keen interest in aviation topics, the lecture series alone cannot involve them enough to consider themselves as practicing engineers.

Concerning the project itself, the common view of students' progress following a negative accelerated function was not seen in the project[12]. The learning curve experienced here was more of a progressive slope type at the beginning of the project and following a gradual asymptote at the end of the project. This resulted to an initial delay and the students were unable to fulfil some of the tasks in time. After the training sessions of the design software system, the students progressed very rapidly. The pressure of the upcoming design reviews intensified their efforts and the tasks were finished in time. Having to learn about basic turbomachinery and the turbomachinery design software in parallel brought students to their limits. In the ideal case, a time lag of six to eight weeks was observed to be necessary before the software is introduced. This period is needed for the basics of the subject to be digested and reasonably established in students' mind. The future exercises will be adapted respecting this introduction phase. Students connected the knowledge gained in the reviewed material, which then allowed them to take the necessary steps and use the software tools, effectively. The progress of the students was very rapid, at this stage. The general process of the project showed a particular development of student focus. The Preliminary Design Review put students down to earth when they realized that not all of the requirements were achieved. Interfaces between the Universities have been mildly disregarded and became a difficult issue in the following common meetings. This improved student interactions, and though not resolving all design criteria, it led to a better understanding of the design process of a complex machine.

The realistic approach leading to recognized results from industry increased self-confidence of the student team and generated a driving force for the design process. The fact that they designed "their" stage independently, the availability of a first three-dimensional geometry, including the cooling passages within a timeframe of fourteen weeks of a semester impressed all participants, industrial mentors as well as the students themselves. Such highly sophisticated output is not likely to be achieved without the introduced computational methods. However, a hesitation of reiterating the process using the same tools has been recorded. Considerations regarding time frames, workload and feasibility lead the students to accept solutions beyond the design criteria and to continue with further steps based on a non-ideal solution.

The effort that had to be put by the academics to get the process going was higher than expected. The high complexity of the task at the early stage of student education invoked the need for longer training compared to conventional design projects. Finally, the coordination with the other University teams and the technical professionals was very time consuming.

Generally, it was found that the more complex the system got, the closer the team moved together. The complex software system was not appropriate to be used by five students at a time, so "specialist team members" were developed. This had the side effect of developing a strong leader and follower structure in technical as well as in organizational aspects. Additionally, the group demonstrated some inertial behavior in forming. The effort that had to be put to form the team and make the students to work together as a coordinated group had to be put again in the second semester to separate the group, when individual tasks needed to be performed. Overall, the students integrated very positively with their local peer group.

Formal student survey

A questionnaire was developed to gather evidence on whether the students appreciated the design project and a future introduction of the turbomachinery design software system into the lectures and exercises. The evaluation contained aspects of support, the application of computational tools, communication and teamwork.

The project was valued as instructive and useful, though the workload was generally considered high. Comments for future projects suggested to better coordinate the accompanying lectures with the project tasks or to restrict participation only to students those have already followed the basic turbomachinery courses. The support and technical training was evaluated positively, but due to the recognized high complexity of the task, further advice was desired especially in the second semester for the individual tasks. The involved software systems were considered to be very useful as well as unavoidable, considering the goals of the project. Surprisingly, in contrast to academic judgement, the students found their performance not being affected significantly by being pioneers in such design project. Students realized difficulties with information exchange and communication with the other university teams and appreciated the learned and applied working techniques. Unanimously they found themselves overcoming cultural differences in engineering practice. Along with common sense they found the personal meetings most useful to overcome these difficulties. Telephone conferences were considered to be useful for direct information exchange and videoconferences for the starting phase were suggested as a future improvement.

Finally, the feedback from the formal survey and the regular informal discussions provided a fruitful basis for the implementation of the design software tool into the future turbomachinery education at ETHZ and also gave positive input for further design projects.

Conclusions

Recent advances in information technology provided engineers with a range of computational and design tools. The role of the University is to prepare the students adequately for the engineering practice and therefore the introduction of sophisticated design tools in modern engineering courses is inevitable. The present design exercise set out to probe the reception of advance computer aided tools for turbomachinery design by a selected group of students.

The main observations were:

- The implementation of the modern design tools has been successful. A future project involving the following generation of students trained in the tools is very promising.
- Initially the learning process was slow and laborious owing to unfamiliarity with the systems involved. A time lag of six to eight weeks has to been registered for the design software to be used effectively and will be taken into consideration for future planning.
- A significantly higher amount of academic support and input was required to achieve the project goals within the given time frame.
- The feeling that students were participating in a pioneering project has improved their work progress, however their self-evaluation yielded moderate respect for this effect.
- A difficulty in applying engineering judgment through the process and reiterate using the same tools has been recorded.
- The students succeeded in integrating within their local peer group and worked well as a team. They showed positive signs of developing leadership skills and succeeded in distributing the tasks.
- Cultural differences appeared to have a significant effect when the students were exposed to the international forum.

For regularly offered classes with few students, this type of project is an ideal solution to motivate students to stay in the field and learn more about design philosophies. Additionally, it generates the multi-disciplinary view of the design at a very early state of education. Once the infrastructure is in place and students are trained in the software, the integration of such project into the normal student curriculum should be less resource intensive.

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